

B&W's Advances on Cyclone NO_x Control Via Fuel and Air Staging Technologies

H. Farzan
G.J. Maringo
D.W. Johnson
D.K. Wong
Babcock & Wilcox
Barberton, Ohio, U.S.A.

C.T. Beard
Eastman Kodak Company
Rochester, New York, U.S.A.

S.E. Brewster
Tennessee Valley Authority
Chattanooga, Tennessee, U.S.A.

Presented to:
EPRI-DOE-EPA Combined Utility Air Pollutant Control
Symposium
August 16-20, 1999
Atlanta, Georgia, U.S.A.

BR-1683

Abstract

Recently, cyclone boiler owners have been installing NO_x control technologies in order to comply with the Title I and Title IV Clean Air Act Amendments (CAAA) of 1990. The Babcock & Wilcox (B&W) Company has been working on the development and implementation of fuel staging (reburn) and air staging technologies. Gas reburn technology has been successfully retrofitted to three Eastman Kodak Company cyclone boilers (Unit No. 43, 42 and 41), located in Rochester New York. From baseline NO_x emission levels, 50-75% reduction is achievable without any negative boiler operating consequences. In addition, B&W has successfully applied the air staging technology to numerous cyclone-equipped units firing a broad range of fuels. The largest of these boilers is TVA's 700 MW_e Paradise Station Unit 1 where 50 to 70% NO_x reductions from baseline levels are being obtained while maintaining acceptable boiler operating conditions.

The paper discusses these commercial applications of the gas reburn and air staged technology retrofits. A key new feature of the Kodak Gas Reburn retrofits is B&W's second generation gas burner design. Improved cyclone air flow measurement techniques at both Kodak and TVA will also be identified.

Introduction

Based on the large range of uncontrolled NO_x emission levels which are apparent in the cyclone-equipped boiler population (0.7 - 2.6 lb/million Btu), various NO_x emission reduction techniques are necessary to meet the industry needs. B&W's low NO_x cyclone experience dates back to the early 1970s with the application of cyclone air staging techniques. Since cyclone NO_x reduction requirements were of minimal concern at that time, testing was terminated after the NO_x reduction potential was proven. In light of present day needs, various commercially available cyclone-equipped boiler low NO_x techniques are avail-

able and these include: 1. Fuel switching, 2. Reburning, 3. Air Staging, 4. Selective Catalytic Reduction (SCR), and 5. Selective Non-Catalytic Reduction (SNCR) technologies.

In addition to the commercially available technologies, numerous other developmental techniques are presently being investigated. The most promising of these are: 1. modified natural gas injection/reburn-type techniques, and 2. water or steam injection.

Virtually all coal-fired units greater than 25 MW_e will be affected by the final Phase II implementation of the "Acid Rain" Title IV of the 1990 Clean Air Act Amendments (Jan. 1, 2000). Units not opting in or controlled under Phase I (1996) will need to comply with emissions limits between 0.40 and 0.86 pounds of NO_x as NO₂ per million Btu input - most having to meet either 0.40 (T-fired) or 0.46 (wall-fired) or 0.86 (cyclone-fired). In addition, Title I (ambient air quality including ozone) will require further reductions predominantly in the 12 northeastern (Ozone Transport Commission, OTC) states plus the Dist. of Columbia in 3 phases eventually reaching 75% reductions or emissions limits of 0.15 lb/10⁶ Btu by 2003.

However, of more long-term significance for coal-fired units are the proposed EPA Ozone Transport Rules or OTR (draft October 1997 and final September 1998). This set of regulations is based upon the recommendations of the Ozone Transport Assessment Group (OTAG) which comprises the 37 states east of the Rockies. The OTR evaluation assumes full compliance with the existing Title I and Title IV regulations plus regional growth through 2007. The OTR then requires an additional reduction from all sources in the designated states during the summer ozone season of May 1 through Sept. 30. Each state will be given a NO_x budget (total tons NO_x emitted) and will be required to develop a state implementation plan.

These rules are fuel neutral and the states have the option of shifting the NO_x reductions between areas. The proposed rules include a market-based "cap and trade" program option which,

if adopted in the state plans, will permit facilities which can achieve greater NO_x emission reduction to sell excess NO_x allowances to those facilities which cannot reduce emissions as effectively.

The proposed utility regulation will, in many cases, be equivalent to emissions limits of 0.15 lb/10⁶ Btu during the summer ozone season. The “cap and trade” proposal will provide an incentive, especially in the largest facilities, to over-comply, similar to the sulfur dioxide (SO₂) control program which is part of Title IV. The bottom line is that NO_x emission limits are headed downward to levels lower than those specified in Title IV.

The timing when all of these rules will be fully implemented on specific units remains somewhat uncertain, and is complicated by the fine particulate matter (PM-2.5) rule also being considered.

Cyclone-equipped boiler owners are actively proceeding with implementation of various NO_x reduction mechanisms. B&W is commercially involved with supplying reburning, air staging, SCR, and SNCR technologies to users to meet the present and/or upcoming regulations. In addition, B&W provides the expertise in the design recommendations and implementation of cyclone users switching to sub-bituminous coals.

This paper presents the theory behind two of these technologies along with corresponding full-scale commercial application and experiences. B&W’s gas reburn technology as applied to three units at Eastman Kodak will be discussed. In addition, two air staging retrofit contracts at TVA’s Paradise Station will be addressed (one retrofit completed and the second in the design/fabrication phase).

General Technology Description

Cyclone Air Staging

The basic theory of air staging is to reduce the fuel NO_x component within the burner zone by reducing oxygen availability. Additionally, the thermal NO_x component will be lowered. Due to the unique combustion characteristics of cyclone-equipped boilers, a higher than typical percentage of the total NO_x generation from a coal fired cyclone application is attributed to the thermal NO_x component. Thus, operating the cyclones at reduced air flow or under stoichiometric conditions (less air than is required for complete combustion) substantially minimizes both fuel and thermal NO_x formation.

Cyclone air staging employs multiple combustion zones within the furnace region, defined as the main combustion (cyclone region) and burnout (OFA ports to the furnace exit) zones. The cyclone main combustion zone is designed to operate at a stoichiometry of about 0.90 to 1.00 (less air than is theoretically required for complete combustion). Operating at higher cyclone stoichiometries is feasible, but at a cost of minimizing the overall NO_x reduction capabilities. Based on start-up activities, the actual operating cyclone stoichiometries would be optimized to provide the required NO_x reduction while maintaining optimum boiler operation.

The balance of the required combustion air is introduced through Overfire Air (OFA) ports. The B&W Dual Air Zone OFA ports are designed with adjustable air velocity controls to enable optimization of mixing for complete fuel burnout prior to exiting the furnace. Other available B&W designed OFA ports include: Circular/Rectangular Port with Integral Louver damp-

ers and Circular/Rectangular Opening with Radiation Shield. Site-specific review for each application is performed to optimize the operation and corresponding cost factors to determine the recommended port design. A satisfactory residence time within the burnout zone is required for complete combustion.

B&W has over 30 years experience with NO_x control systems utilizing staged (and/or biased firing) combustion techniques in natural gas, oil, and coal fired boilers. Early development in the 1960s led to B&W’s initial patent based on the company’s efforts in Southern California. Initial low NO_x cyclone experience via air staging dates back to the early 1970s. Two (2) short term air staging tests were performed at Commonwealth Edison’s Will County Station and the Board of Public Utilities Kansas City. Will County used the gas recirculation ports to simulate the overfire air (OFA) port system and new dedicated rectangular openings located around the cyclone throats were provided at Kansas City.

Present day state-of-the-art overfire air (OFA) port systems are a routine offering which B&W can supply on a turnkey basis to meet stringent low NO_x emission level requirements while firing a variety of fuels in numerous furnace configurations. Cyclone-equipped boiler air staging applications have been demonstrated on numerous units ranging from ~125 to 700 MW. Numerous other cyclone-equipped boiler users are presently investigating and/or implementing OFA systems to help meet their overall NO_x control strategy. Table 1 lists B&W present cyclone air staging experience.

Based on all the positive results obtained to date, a multitude of utilities have determined that air staging is to be an integral part of their overall NO_x control strategy and are requesting proposals for the supply of OFA systems to meet their NO_x emission requirements.

Although good NO_x reduction via air staging can be achieved, long-term operation is required to fully evaluate the pros and cons of this low NO_x reduction alternative technology on cyclone-equipped boilers. Questionable cyclone and lower/upper furnace life expectancy due to potential corrosion concerns is a possibility while operating under reducing conditions. The magnitude of the corrosion problem needs to be more fully addressed. Utilizing lower sulfur/iron fuels, such as lignite or low sulfur sub-bituminous coals, will aid in reducing these concerns. Co-firing coal with such fuels as petroleum coke or tire derived fuel (TDF) will also potentially aggravate this concern. In addition, other potential negative long term operational aspects include higher unburned carbon levels, increased boiler flyash percentages (higher particulate loading), increased boiler slagging/fouling, and higher opacity levels. Even though these issues require long term operational evaluation, all preliminary indications reveal that the boiler operational issues (unburned carbon, slagging /fouling, opacity, etc.) have not materialized.

Key issues which need to be addressed in order to assure adequate cyclone/boiler operating conditions include accurate air flow measurement and control of the OFA port system, and the total air flow to each individual cyclone. The air flow measurement at the cyclones should include secondary and primary/tertiary air. This will provide the capability to improve the cyclone air/fuel relationship and this will help lead to maintaining acceptable cyclone operating characteristics. Improved accuracy of the existing plant’s economizer outlet oxygen (%O₂) indication is also desirable to enhance operating performance. Maintaining the existing cyclone burner pressure drop (windbox to furnace differential) at normal operating levels (or if the capa-

Table 1
B&W Cyclone Air Staging Experience List

Unit Size, MW	Status	Fuel Type	Reduction, %
700	Operating	Bituminous	50-70
700	Design/Fabrication	Bituminous	-
574	Design/Fabrication	Sub-Bituminous, Pet Coke	-
605	Design/Fabrication	Sub-Bituminous	-
500	Operating	Sub-Bituminous	50-70
125	Operating	Bituminous	40-60
225 (4 units)	Design/Fabrication	Bituminous	-
1150	Pending	Bituminous	-

bility exists, higher than normal) is necessary to keep good operating conditions. Additionally, good cyclone operating practices must also be followed/maintained (coal fineness, minimize re-entrant throat size/gaps, optimize primary/tertiary air flows, good refractory coverage, accurate coal feeder operation, etc.).

General Reburning Description

The reburning process employs multiple combustion zones in the furnace, defined as the main combustion, reburn, and burnout zones. Reburning is a process by which NO_x produced in the main burner combustion zone is reduced (decomposed to molecular nitrogen) in the main furnace by injection of a secondary fuel. The secondary (or reburning) fuel creates an oxygen-deficient (reducing) region and creates hydrocarbon radicals that react with and decompose NO_x molecules. Since reburning can be applied while the main burners operate under oxidizing conditions (or under slightly reducing conditions), the effect on main burner zone performance is minimized.

B&W's reburning technology involves removing approximately 10-30% of the heat input from the main combustion zone and replacing it through new reburn burners located above the main burner zone. B&W experience includes firing gas, coal, oil, and coal-water slurry as the reburn fuel to achieve NO_x reduction.

The main burner combustion region could be operated at nominally less than theoretical air to ~10% excess air (0.95 to 1.10 stoichiometry) in order to assure stable operation and help minimize potential tube corrosion issues. Accurate air and fuel measurement and controllability are required to maximize reburning effectiveness and minimize boiler operational effects. The new reburn burners will be operated at sub-stoichiometric conditions (~0.20 - 0.30 stoichiometry for gas reburning) in order to create an in-furnace reburn zone stoichiometry of approximately 0.80 - 0.90. B&W's reburn burners are operated in a similar fashion as standard wall fired burners (including flame safety and lighter systems). The remaining air necessary for complete combustion is then introduced through new Overfire Air (OFA) ports located in the upper furnace region (totaling about 15-20% excess air or a 1.15 to 1.20 stoichiometry at the furnace exit). Depending on the specified reburn fuels, strict residence time criteria within the reburn and burnout zones have been developed and are critical to successful reburn operation.

Since the NO_x reduction occurs within the furnace zone between the new reburn burners and the NO_x ports, the mixing between the reburn fuel/air flow and the existing main burner combustion gases is a key design variable. An option to promote improved mixing capability would be to introduce gas re-

circulation (GR) to the reburn burners. Field experience has shown that similar NO_x reduction capability is achieved without the use of GR. Numerical modeling is recommended to evaluate the various design features and fully optimize the reburn system design.

B&W initiated activity in the reburn technology in the mid-1980s. Proof-of-concept pilot-scale testing was followed by a successful full-scale application of the coal reburning technology at Wisconsin Power & Light's 110 MW Nelson Dewey Unit 2. In addition, three (3) successful gas reburn retrofits at Eastman

Kodak Park in Rochester, N.Y. have been completed. All commercial guarantees have been met and Kodak continues to operate the systems to meet their emission level requirements.

TVA Paradise Station Cyclone Overfire Air Project

Paradise Plant

TVA's Paradise plant, located in western Kentucky, is a coal fired generating plant consisting of three Babcock & Wilcox Cyclone fired once-through type boilers. Units 1 and 2 are identical sub-critical 700 MWe units and Unit 3 is a super-critical unit rated at 1150 MWe. Although Unit 1 (PAF 1) is the subject unit of this paper, duplication of the OFA system on PAF 2 is currently in the design and fabrication phases. TVA also has plans to incorporate a similar system on PAF 3.

Boiler Information

PAF 1 was originally installed in the early 1960s. The boiler is designed to produce 4,900,000 lb/hr main steam flow at 1053F and 2,450 psig at the superheater outlet. The firing system consists of 14 - 10 ft diameter Cyclone furnaces, arranged 7 in the front wall and 7 in the rear wall. The boiler originally included a flue gas recirculation system with ports located 18 feet above the cyclones. The GR system also fed tempering gas ports that had been removed from service years ago. The boiler was originally designed as forced draft but was converted to balanced draft operation in 1980. A sectional side view of the boiler is shown in Fig. 1.

TVA's Technology Options/Evaluations

TVA performed an evaluation to determine the most effective means of NO_x control to meet the Title IV requirements. The technologies initially considered included: gas reburn, coal water slurry and coal reburn. Of these technologies coal reburn was determined to have the lowest evaluated cost for this application.

Prior to significant design of the coal reburn system, TVA learned of successful installation of overfire (OFA) air through its participation in Cyclone NO_x Controls Interest Group (CNCIG). Of particular interest were the results obtained by the demonstration at the AmerenUE Sioux Plant. Based on the potential shown for getting comparable NO_x reductions at lower capital cost, TVA deferred coal reburn design until OFA was evaluated for this application.

Through CNCIG, Reaction Engineering International (REI) was contracted to perform a computer modeling study to evalu-

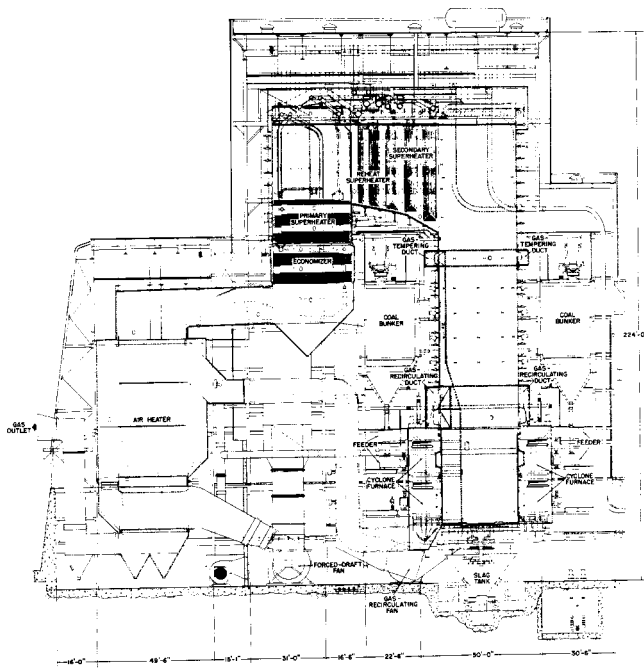


Figure 1 Sectional side view of PAF 1.

ate the feasibility of installing OFA on Paradise unit 1. The study addressed the following: NO_x reduction predictions, basic design of the system (elevation, number of injectors, spacing, orientation), furnace exit temperature and CO predictions, and the potential corrosion rates on boiler tubes.

After baseline conditions were established, the model was used to evaluate the impacts of OFA at three (3) different furnace elevations for a variety of cyclone stoichiometries. The most effective NO_x reduction was achieved at the highest evaluated furnace elevation, with the OFA nozzles located 40 feet above the existing gas recirculation ports.

Although TVA initially considered pursuing the higher elevation OFA installation, the final configuration was chosen based on the following: minimize the overall risk for waterwall corrosion in the reducing/oxidizing zone, utilizing OFA as a substitute for existing gas recirculation system, and minimize capital cost by eliminating need for extensive OFA supply ductwork.

For the case, as installed, the REI model predicted NO_x reduction of 55% at a cyclone stoichiometry of 0.95 and a 72% reduction at a cyclone stoichiometry of 0.90. At these conditions, both the furnace outlet temperature and outlet CO were predicted to be slightly lower than baseline values. The model was also useful in specifying the nozzle outlet velocity.

After evaluation of the test results, TVA contracted with Babcock & Wilcox to conduct flow and circulation modeling to confirm that the function of the gas recirculation system could be effectively replaced by the OFA system.

Manufacturer's Scope of Supply

Babcock & Wilcox began its work by calculating predicted performance of the unit at start-up and various load conditions without gas recirculation. Once full load conditions were established, Babcock & Wilcox performed computer modeling of the furnace to help establish quantity, size and location of the new ports for optimum fuel-air mixing above the cyclones.

Nine (9) Babcock & Wilcox Dual Air Zone overfire air (OFA) ports, 5 for the front wall, 4 for the rear wall, were furnished. The existing gas recirculation ports could not be re-used due to their size, so they were replaced with new openings designed specifically for the new ports.

The Dual Air Zone ports allow the overfire air flow through each port to be controlled and monitored individually for optimum performance. They are designed to provide optimum mixing between the balance of combustion air being introduced through the OFA ports and the gases from the lower furnace zone. The outer annulus of each port is equipped with manually adjustable spin vanes, designed to provide sufficient dispersion of air for mixing near the furnace walls. The inner (or core) air zone ensures that penetration is sufficient to promote mixing towards the center of the furnace and is controlled with a manual core damper. A total air damper per port is also available and it is manually adjusted and set at one opening for all loads.

Each OFA port is equipped with two (2) air measuring devices that provide a relative indication of air flow entering each OFA port. These air measurement devices provide flow indication locally at each OFA port to facilitate balancing of the air flow to each port during commissioning.

Babcock & Wilcox re-designed the existing gas recirculation windbox in order to handle the resultant higher secondary air pressure, which exists at the new OFA ports. This was done by augmenting the existing system of stiffeners and ties. These modifications were accomplished without affecting main support steel and required no relocation of existing equipment.

The gas recirculation plenum wrap-around is located directly above the secondary air windbox wrap-around and separated by an 18 inch gap. This gap on both sides of the boiler was bridged with a short duct to supply secondary air to the GR windbox. Air Monitors, control dampers, splitter plates and turning vanes were furnished to control and distribute the air to front and rear ports. The gas recirculation supply connections were blanked off.

Since precise air flow measurement is important to maintaining proper stoichiometries, TVA decided to install air flow measurement devices at all major air entry points in the furnace, including the cyclone secondary and primary/tertiary air entrances. Industry standard air flow monitors are used to measure the OFA and primary/tertiary flows. Due to the unique inherent design of the cyclone secondary air system, a prototype air measuring device is utilized. Future additional calibration checks of this device are planned to verify their accuracy. The Air Monitor Corporation supplied all the air measuring equipment for this contract.

Design Criteria

Each application for an OFA port system is considered on a unit specific basis taking into consideration overall unit geometry, intended fuel types, burner zone heat release rates, combustion system characteristics, and required target emission levels. The OFA system's responsibility is to effectively introduce the balance of combustion air necessary to complete combustion prior to the boiler's furnace exit. The system is comprised of furnace wall openings located above the top elevation of the furnace stud line. B&W's Dual Air Zone OFA Ports are used to introduce the overfire air flow through each of these openings. The final location and sizing of the OFA ports are determined with the aid of B&W's patented numerical models.

Table 2
Summary of Typical Coal Analysis

As-Received Coal Analysis	Total Moisture, %	Ash, %	Sulfur, %	Carbon, %	Hydrogen, %	Nitrogen, %	Oxygen, %	HHV (BTU/#)
1-6-99	11.77	8.63	2.92	64.86	4.03	1.05	6.74	11,722

The general criteria used to design the OFA port systems at PAF 1 & PAF 2 include:

- Cyclone stoichiometry = 0.90
- Excess air leaving the combustion zone = 20%
- Secondary air temperature = 590F
- Nominal OFA port velocity @ MCR load = ~18,000 ft/min
- Cyclone windbox to furnace differential pressure (coal firing) = 36 in. w.c.

One of the major criteria B&W initially utilizes to evaluate the potential of a staged system is furnace residence time. Sufficient time within the furnace region is required to achieve complete burnout of the fuel prior to the boiler's furnace exit. Numerical modeling was used to confirm that optimized mixing potential of the overfire air and the cyclone combustion gases could be obtained with the proposed OFA arrangement.

Start-up and Combustion Optimization

The OFA system was installed in the fall of 1998 with the boiler start-up occurring in early November. Optimization tests of the OFA system were conducted from December 10 through January 21. This testing was performed to assess unit performance (i.e. flue gas emissions, flyash analyses, boiler efficiency, etc.) under various operating OFA system conditions. At MCR load conditions (~680 MW), cyclone stoichiometry was varied along with testing various OFA port component positions (varied individual port spin vanes and core zone disks). In addition, low load operation was tested to confirm the system's capabilities at reduced loads (456 MW).

Flue gas emission levels and temperatures were measured at the air heater inlet and outlet locations using a grid system in accordance with standard EPA methods. A total of 30 test points were used at the inlet and 48 points at the outlet. NO_x, O₂, CO, and CO₂ emission levels were measured at each location. Flyash samples were collected isokinetically from 4 ports at 3 points

per port on each of the airheater outlet ducts. Coal and flyash samples were collected during each of the tests and subsequently analyzed at TVA's Central Laboratory.

The majority of the tests were performed while firing 100% bituminous coal. Table 2 shows a typical analysis of the coal fired throughout the optimization test phase. A few tests were performed at the end of the optimization work using various quantities of PRB coal. Although the results of those tests are not presented here, the data reveals that very similar operation was apparent when blending 20 and 50% PRB with TVA's base bituminous coal.

Generally speaking, the start-up of the OFA port system occurred without incident. The transition to operating under cyclone air staged conditions was very smooth. The potential negative side effects such as cyclone/furnace slag tapping problems, substantially higher unburned carbon levels, higher flyash loading, higher CO emission levels, and higher opacity did not materialize. Operationally, the OFA system has been a seamless addition to normal boiler operation. The system operates, the NO_x is reduced, and no major problems are observed.

Long term operation is required to confirm that no major problems are encountered. Cyclone and lower furnace corrosion is one main parameter that requires long term operation to fully assess. Operating at reduced air flows to the cyclone can also increase the potential for iron puddle formation. If this occurs, increased operational problems can result (e.g. slag tapping, increased maintenance, unburned carbon, flyash loading, and opacity problems).

Emissions and Performance Data Summary

Eleven (11) OFA system optimization tests were conducted at PAF1. Results of these tests showed that a substantial reduction in NO_x emission levels could be achieved. The data established a maximum and minimum NO_x level that can be obtained

while maintaining acceptable boiler operating conditions. Prior to the installation of the OFA system, a series of baseline tests were performed to provide a direct comparison to the post-retrofit results. The initial optimization of the OFA system was to achieve below 0.86 lb/million Btu NO_x emission levels (EPA Title IV, Phase II requirement for cyclone boilers). A brief summary of the baseline tests and the typical OFA operating data are shown in Table 3.

Table 3 shows that the optimization test results proved that the NO_x emission levels can be maintained at below the targeted 0.86 lb/million Btu level while operating over the boiler's load

Table 3
Baseline and OFA Optimization Summary

Performance Parameter	Baseline Test Results	Optimization Test Results
NOx Emission Levels		
- MCR Load (average)	1.61 lb/million Btu	0.83 lb/million Btu
- Low Load (average)	1.32 lb/million Btu	0.82 lb/million Btu
CO Emission Levels		
- MCR Load (average)	< 1 ppm	< 1 ppm
- Low Load (average)	1 ppm	< 1 ppm
Flyash Loss on Ignition		
- MCR Load (average)	1.57%	2.07%
- Low Load (average)	1.71%	3.57%

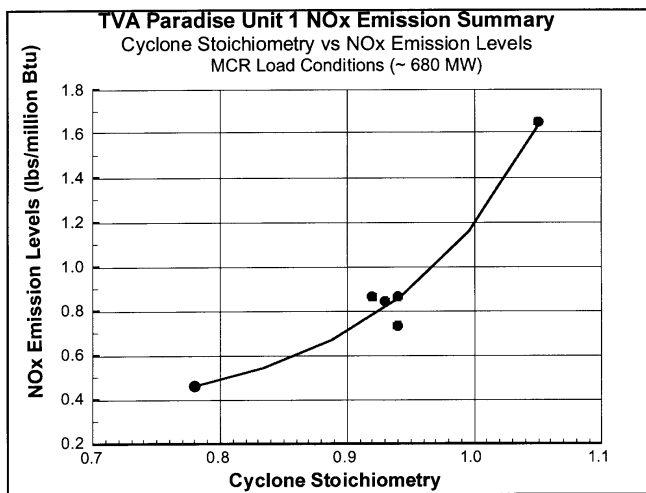


Figure 2 TVA Paradise Unit 1 NO_x emission summary.

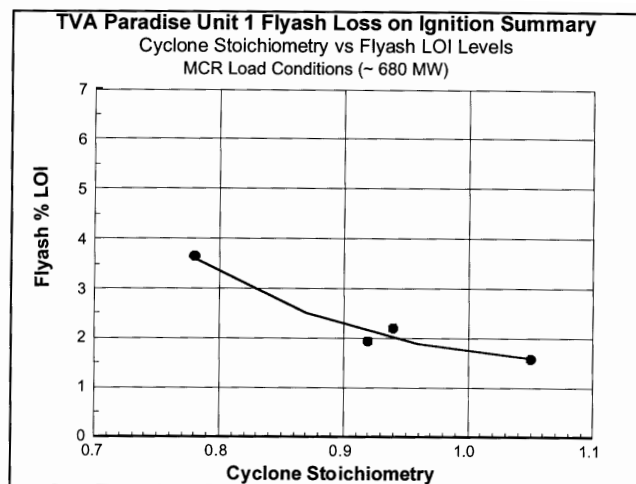


Figure 3 TVA Paradise Unit 1 LOI emission summary.

range. No impact on CO emission levels and only a minimal increase in loss on ignition (LOI) values are observed from baseline conditions.

At MCR load (~680 MW), cyclone stoichiometry was varied to assess the NO_x reduction capability of the OFA system. The % of OFA flow as a function of total air flow (while maintaining total air flow as constant as possible) was varied to achieve the different cyclone stoichiometries. Fig. 2 reveals the results of varying cyclone stoichiometry and the resultant NO_x emission level. Baseline (minimum OFA flow) NO_x emission levels were 1.65 lb/million Btu during this test phase. Reducing the cyclone stoichiometry to ~0.92 to 0.93 results in approximately a 50% NO_x reduction from baseline levels (0.83 lb/million Btu). Lowering the cyclone stoichiometry to as low as possible by maximizing the OFA flow resulted in a NO_x emission level of 0.46 lb/million Btu. This equates to a 72% reduction from baseline levels.

During the NO_x reduction testing, flyash samples were collected to evaluate LOI levels. Fig. 3 shows the results of cyclone stoichiometry versus LOI. The base % LOI during the minimal OFA flow test was at 1.57% and this is considered very

low for typical cyclone operation. Operating at ~0.92 to 0.93 cyclone stoichiometries resulted in a slightly higher LOI of about 2.07%. The lowest cyclone stoichiometry tested showed a LOI level of 3.64%. Although higher than the baseline, all of these LOI levels are considered low for typical cyclone operating conditions.

Throughout the testing phase, another key variable with this retrofit was to identify superheat (SH) and reheat (RH) temperatures. As discussed earlier, the gas recirculation system was removed from service during this low NO_x system retrofit. The original design purposes of the gas recirculation system were to provide required mass flow to achieve/maintain design steam temperatures and to also assure furnace wall protection from overheat conditions over the boiler's load range. In order to maintain acceptable boiler operation without gas recirculation mass flow, excess air is used as its substitute. During the full load MCR testing, the economizer outlet O₂% (dry, volume basis) was maintained at approximately 3.1 to 4.0 %O₂. Baseline (minimal OFA flow condition) SH and RH temperatures were 1029 and 1010F, respectively. Optimized tests with the OFA system in service while meeting NO_x emission requirements showed that no change in steam temperatures was observed.

Eastman Kodak Park Cyclone Gas Reburn Projects

Kodak Boilers 41 & 42 Information

Eastman Kodak's Units 41 and 42 are identical B&W two drum Stirling Power Boilers built in 1964 (contract #S-10112) and 1965 (contract # S-10198), respectively. The units were originally designed to burn bituminous coal and/or fuel oil to produce a maximum continuous rating (MCR) of 400,000 lb/hr steam flow, and a 4-hour peak rating of 440,000 lb/hr. These conditions are based on a design pressure of 1575 psig, 345F feedwater temperature, and a secondary superheater outlet temperature controlled to 900F. The furnace dimensions are 20.92 ft wide by 5.71 ft deep at the cyclone burner level, increasing to 11.92 ft deep in the upper furnace. The unit is front wall fired using two (2) eight foot diameter cyclones. Fig. 4 shows the sectional side view of the originally supplied boiler.

Retrofit Description

Babcock & Wilcox's second generation gas reburning system design was retrofitted at Eastman Kodak's cyclone-equipped Boiler 41 in December of 1998. This is a duplicate design to that supplied on Kodak Boiler 42 in July of 1998, except that additional gas spud design arrangements were available for optimization testing. In addition, Kodak Boiler 43 (550,000 lb/hr steam flow, cyclone-equipped, Stirling Boiler) had been successfully implemented with B&W's first generation gas reburn system in 1995 (reference August 1997 EPRI-DOE-EPA Symposium, "NO_x Control using Natural Gas Reburn on an Industrial Cyclone Boiler"). One key difference with this original retrofit was the use of gas recirculation to the reburn burners to enhance reburning effectiveness.

A new modified B&W S-type reburn burner design is used in the reburn systems supplied on Boilers 41 & 42. Two (2) 14 in. throat diameter S-type gas fired burners are supplied per boiler. The furnace wall tubes in the burner area are bent to form the reburn burner throat. The burners are located 1 per each sidewall and are positioned above the main cyclone combustion zone slag line.

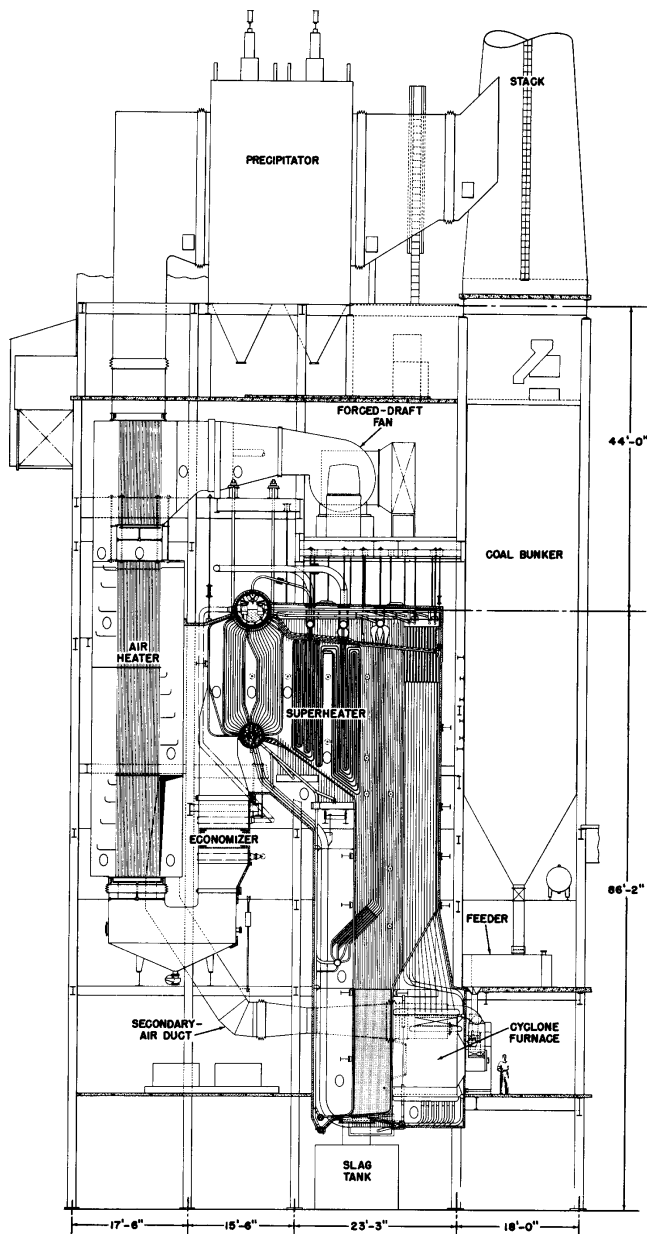


Figure 4 Sectional side view of the originally supplied Kodak Boilers 41 and 42.

The natural gas fired S-burner is comprised of two air zones: the inner or core zone and the outer secondary air zone. Total reburn burner secondary air (SA) is introduced to each individual reburn burner. Automatic dampers and air monitors located in each of the ducts leading to the reburn burners are used to control total SA flow to individual reburn burners. The reburn burner design is unique in as much as the burner assembly includes both the burner and windbox as a single component. This allows for easier installation.

Each burner is equipped with a direct ignition lighter system. A retractable High Energy Ignitor (HEI) is located near the main gas spuds and used to directly light the main gas flow. The HEI is inserted/energized just prior to opening the main burner gas valve and then is retracted after the trial for ignition period.

Flame detection equipment is also provided on each burner. Two (2) flame scanners per burner are available for detection of individual main burner gas flames (one scanner is physically located at the burner centerline and the second is positioned at the observation port located just above the burner). The scanners are intended to ensure safe and proper sequence of start-up and normal operation.

Secondary air is introduced to the core zone by means of slots located around the periphery of the inner sleeve. Secondary air to this zone is controlled by means of a sliding disk designed to regulate flow as required for combustion. A manually operated pull handle, penetrating the coverplate, is attached to the sliding disk to permit linear adjustment. A minimum of secondary air is required in this zone for optimum combustion. The core zone also houses the main gas fuel elements (four modified Hemi-type gas spuds per burner are available).

The majority of SA enters the S-burner into the outer air zone. Within this zone, a perforated plate exists to evenly distribute the secondary air flow and improve flame stability. One thermocouple per burner is also available to monitor burner metal temperatures.

Natural gas is supplied to the plenum manifold of each burner. The manifold is located outside of the windbox for accessibility to the gas elements. Gas is distributed from the manifold to each of four (4) individual gas elements housed in the core zone of the burner. Each gas element is in turn housed in a carrier pipe to position and secure the element properly in the burner. The gas element assembly is designed to permit removal and/or rotational adjustment of individual gas spuds.

Distinctive features of this design are:

- The individual gas spuds are removable with the burner out of service to enable cleaning and re-drilling of the gas nozzles as required.
- The individual gas spuds can be rotated to orient the gas nozzles for optimum firing conditions with the burner in service.
- The location of the individual gas spuds with respect to the burner throat can be varied a limited distance to obtain optimum firing conditions with the burner in service.

The OFA ports introduce the balance of air for complete combustion and a sufficient mixing/residence time criteria prior to the furnace exit is also required. B&W's Dual Air Zone OFA port is designed to provide optimum mixing of air and flue gas in the second stage of combustion. Four (4) total ports are available on the front wall per each boiler. The ports are located in between the 3 sets of cyclone riser tubes. The 2 center ports are 14 in. throat diameter while the 2 outermost ports are 20 in. The outer annulus of the 20 in. diameter outermost ports are equipped with eight interlinked manually adjustable spin vanes, designed to provide sufficient dispersion of air for mixing near the furnace walls. The inner air zone provides the capability to ensure that air flow penetration is sufficient to promote mixing across the depth of the furnace. A sliding disk is available to control this inner zone air flow.

The 14 in. diameter innermost ports are designed with no adjustable spin vanes. The outer air zone contains a perforated plate to help evenly distribute the air flow leaving this zone. The inner air zone provides the capability to ensure that air flow penetration is sufficient to promote mixing across the depth of the furnace. A sliding disk is available to control this inner zone air flow.

Each OFA port is equipped with an air measuring device and thermocouple to monitor relative air flow and metal temperatures.

The following summarizes the results from each of the gas reburn retrofits at Eastman Kodak. Although the results from Boiler 41's retrofit are similar to that achieved on Boiler 42, the new gas spud design options did slightly improve overall system operation. In addition, the data also identifies that the second generation B&W gas reburn system not only provides a simpler, more reliable system, but also improves the NO_x reduction capabilities.

Results

The data evaluation in this document includes resultant NO_x emission levels (lb/million Btu) versus % natural gas heat input at MCR (400,000 lb/hr steam flow for Boilers 41 and 42 and 550,000 lb/hr for Boiler 43) load conditions. In addition, NO_x emission levels during optimized automatic control conditions over the boilers load range (Peak load @ 110% MCR to ~30% steam flow) are summarized.

Babcock & Wilcox maintained a continuous emission measurement (CEM) system at the boilers' economizer outlet capable of measuring NO_x, CO, and O₂ levels. In addition, a boiler diagnostic system was operational to determine boiler performance and furnace stoichiometries. Key variables that were varied to evaluate the gas reburn process include natural gas heat input percentages, gas spud design arrangements, reburn burner air flow rates, and boiler loads. Kodak's initial NO_x emission level requirements are to achieve below 0.60 lb/million Btu. Potential future reduction requirements could be as high as 75% reduction from 1990 baseline NO_x emission levels.

Fig. 5 shows NO_x emission levels (per B&W's CEM system) versus % of total boiler heat input from natural gas at MCR load for each of the three operating gas reburn systems at Kodak Park. At MCR load, pre-retrofit 1990 baseline NO_x emission levels were approximately 1.20 and 1.25 lb/million Btu for Boilers 41/42 and Boiler 43, respectively. Lower overall NO_x emission levels at various gas heat input ratios are apparent between the second generation design installed on Boilers 41/42 vs. the original Boiler 43. The lower NO_x values on boilers 41/42 are due to two factors: lower overall starting baseline (no reburning) NO_x levels on Units 41/42 and also a slight improved efficiency with the new design applied to those boilers. For Boiler 42, varying gas heat from 10.7, 15.9, 24.5, and 28.3%, the corresponding B&W CEM data revealed % NO_x reductions from 1990 baseline levels of 46, 59, 73, and 78% respectively. Boiler 41 results revealed a slight improvement from these levels and are explained via a revised new gas spud design and subsequent optimization testing.

Based on all the start-up tests, optimized operating conditions were identified and incorporated into each of the unit's control systems. The optimized curves included load versus total natural gas flow and reburn burner stoichiometry. Fig. 6 identifies NO_x versus percent of MCR load after the new optimized control curves were incorporated into the boiler's operating scheme. Ramping load from 110% to as low as 63% of rated steam flow resulted in NO_x emission levels that averaged ~0.57 lb/million Btu for Boiler 43. Boilers 41 and 42 averaged ~0.49 and ~0.52 lb/million Btu, respectively, as the units were ramped for 110% to 75% load. Natural gas heat input ranged from about

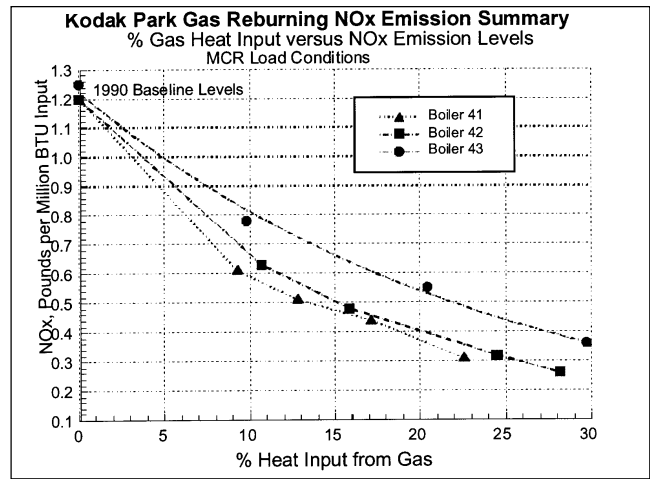


Figure 5 Kodak Park gas reburning NO_x emission summary—percentage of gas heat input versus NO_x emission levels MCR load conditions.

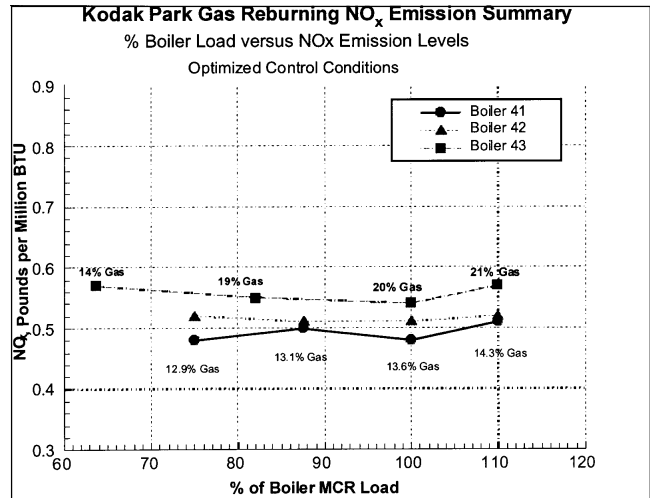


Figure 6 Kodak Park gas reburning NO_x emission summary—percentage of boiler load versus NO_x emission levels optimized control conditions.

21% to 14% at peak load to minimum on Boiler 43. Boilers 41/42 resulted in a natural gas heat input range of ~12.9 to 14.3% at minimum to peak loads.

These heat input levels were optimized during the parametric tests to assure that less than 0.60 lb/million Btu NO_x level was maintained. A gas flow bias station is available to the operator to vary the gas heat input based on maintaining required NO_x emission levels. Although these results were very consistent throughout the testing phase, long term evaluation is required to fully assess the system's capabilities.

The following highlights the main conclusions obtained from the optimization testing of Boilers 41 and 42:

- Using the B&W CEM system, typical NO_x emission levels could be maintained below 0.60 lb/million Btu at MCR load with a maximum amount of natural gas heat input of about 12%. To achieve the same results at low load, the % gas heat input can be reduced to about 10%.

- Lower NO_x emission levels can be obtained at higher gas heat input rates. Using ~28.3% natural gas heat input at MCR load resulted in a B&W CEM NO_x emission level of 0.26 lb/million Btu or a 78% NO_x reduction from 1990 baseline NO_x emission levels. Although the system was optimized to operate at this condition, no long term tests were performed.

- Numerous gas spud design arrangements were tested to optimize NO_x, CO, and overall burner performance. The optimized design ended up being a modified version of B&W's standard Hemi gas spud. Operating at about 20 psig gas pressure at the burner provides good conditions for both lower NO_x and CO emission levels while maintaining a strong scanner flame indication.

- During reburning operation, the economizer outlet O₂% setpoint could be normally maintained at 2.9% on the east and west sides. This provided acceptable conditions to maintain low CO emission levels while also minimizing NO_x emissions.

Boiler Impacts

The reburn technology, if designed appropriately, has shown little impacts on the boiler operation and steam generation. The specific concerns will be discussed below.

Unburned Combustibles Losses. The gas reburn technology has a minimal impact on unburned combustibles. Baseline LOI levels vary between 5 to 15% over the boiler load range compared to 8 to 15% during gas reburning. Typical average CO emission levels can be maintained below 250 ppm. Since the boiler economizer outlet O₂ trim is controlled independently from east to west, excellent O₂ balance can be maintained with resultant good CO emission levels.

Boiler Operations Experience. Smooth transition from baseline to reburn conditions has been Kodak's experience to date on all three boilers. The majority of the optimization tests on Boilers 41, 42 and 43 were performed at 10 to 20% gas in order to achieve the targeted 0.6 lb/MBtu of NO_x emissions. The boiler temperature profile, FEGT, and convection pass tube temperatures are within acceptable ranges. Under these optimized conditions, automatic boiler load control operates efficiently. One feature that was identified revealed that these boilers required additional oxygen probes at the economizer outlet to consistently measure/control the boiler oxygen concentrations accurately.

Tube Corrosion Evaluation. Since gas reburn is accomplished by operating a portion of the furnace in a reducing atmosphere, potential corrosive conditions could exist. During the design of the reburn systems, special attention was given to the reburn burners in order to provide sufficient natural gas penetration and distribution in the boiler, thereby reducing the potential for boiler tube wastage. To evaluate potential furnace corrosion, a furnace tube thickness study was performed before and after operating approximately 15 months. The results showed that no change in tube thickness was identified.⁽¹⁾ Kodak continues to monitor the boiler tubes visually during outages for potential long term effects, but no problems have been identified to date after 3 1/2 years of reburn operation.

Economical Evaluation. An economical analysis was performed to evaluate the cost of the reburn technology for small cyclone boilers. It should be mentioned that both capital and operating costs are site-specific. The capital cost depends on the size of the unit, ease of the retrofit, availability of natural gas at the plant and the control system upgrade requirements. The amount of the gas usage and the differential gas to coal price determine the operating cost.

The gas reburn systems at Kodak Park were more capital intensive due to the customer's need for new boiler controls. For the first demonstration on Boiler 43, a FGR fan and associated equipment was installed to fully characterize the reburn technology potential. Additional costs occurred due to the first-of-a-kind demonstration nature of the project. The economical evaluation for Boiler 43 has been documented previously.⁽¹⁾ The total capital cost was approximately \$5.9 million. Boilers 41 and 42 capital cost was approximately \$3 million. Larger units would benefit from the economy of scale, such that the capital cost of a gas reburn system would typically fall into the \$10-20 per kW range.

The differential cost of gas and coal is the main component of the operating cost. For Boiler 43, the gas/coal differential price was \$1.74/MBtu. The levelized cost of NO_x reduction for Boiler 43 is \$1335/ton of NO_x removed.⁽¹⁾ Boilers 41 and 42 economics are more favorable since less gas was used in these boilers than in Boiler 43. While a full economic study was not performed, the levelized cost is approximately 50% of Boiler 43.

It should be mentioned that both capital and operating costs are site specific. The analysis does not include the additional advantage of the gas reburn in reducing SO₂, and CO₂ emissions. Also, larger units benefit from the economy of scale resulting in reduced capital cost per KW of capacity. The operating cost evaluation has a strong dependence on gas to coal cost differential and must be determined on a site specific basis.

Summary and Conclusions

Lowering NO_x emission levels via combustion-related technologies is a key first step for cyclone-equipped boilers to economically achieve present/future low NO_x emission regulations. Although various low NO_x combustion techniques are commercially available, long term operating experience using these technologies on cyclone boilers is limited. A rapidly expanding low NO_x system retrofit users list is helping to minimize the concerns associated with these applications.

The full-scale commercial applications of both the cyclone gas reburning and air staging technologies reported herein have shown the capability to reduce NO_x emission levels by 50-70% from baseline levels. All low NO_x system retrofit contractual obligations have been met at both Kodak Park and TVA's Paradise Station. The gas reburning and air staging systems continue to operate to achieve the present regulated NO_x emission levels required at these facilities. Long term operational monitoring at these units will be maintained to assure that acceptable conditions remain over time.

References

1. H. Farzan, et al, "NO_x Control Using Natural Gas Reburn on an Industrial Cyclone Boiler," presented at the EPRI-DOE-EPA Combined Utility Air Pollutant Control Symposium, Washington, DC, August 25-29, 1997.

Copyright © 1999 by The Babcock & Wilcox Company,
All rights reserved.

No part of this work may be published, translated or reproduced in any form or by any means, or incorporated into any information retrieval system, without the written permission of the copyright holder. Permission requests should be addressed to: Market Communications, The Babcock & Wilcox Company, P.O. Box 351, Barberton, Ohio, U.S.A. 44203-0351.

Disclaimer

Although the information presented in this work is believed to be reliable, this work is published with the understanding that The Babcock & Wilcox Company and the authors are supplying general information and are not attempting to render or provide engineering or professional services. Neither The Babcock & Wilcox Company nor any of its employees make any warranty, guarantee, or representation, whether expressed or implied, with respect to the accuracy, completeness or usefulness of any information, product, process or apparatus discussed in this work; and neither The Babcock & Wilcox Company nor any of its employees shall be liable for any losses or damages with respect to or resulting from the use of, or the inability to use, any information, product, process or apparatus discussed in this work.